SYNCHRONIZATION OF CAMERA IMAGES IN CAMERA-BASED TOUCH SYSTEM TO ENHANCE POSITION DETERMINATION OF FAST MOVING OBJECTS

Field of the Invention

[0001]   The present invention relates generally to camera-based touch systems and in particular to synchronization of camera images in a camera-based touch system to enhance position determination of fast moving objects.

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Background of the Invention

[0002]   Camera-based touch systems that use cameras to acquire images of a touch surface and process the image data to determine the position of a pointer relative to the touch surface are known. For example, International PCT Application No. WO 02/03316 to Smart Technologies Inc. et al discloses a camera-based touch system including a passive touch surface and a plurality of cameras associated with the touch surface. The cameras have overlapping fields of view encompassing the touch surface. The cameras acquire images of the touch surface from different locations and generate image data. A processor receives and processes the image data generated by the cameras to determine the location of a pointer captured in the images relative to the touch surface using triangulation.

[0003]   In order to triangulate the position of the pointer accurately, especially in situations where the pointer is moving quickly across the touch surface, it is necessary to synchronize the cameras. This is due to the fact that if the cameras are not synchronized, each camera will capture an image of the pointer at a different time and therefore, will see the pointer at a different position on the touch surface. This of course makes the results of triangulation unpredictable and inaccurate.

[0004]   It is therefore an object of the present invention to provide a novel system and method for synchronizing camera images in a camera-based touch system to enhance position determination of fast moving objects.

Summary of the Invention

[0005]   According to one aspect of the present invention there is provided in a camera-based touch system including at least one pair of cameras having overlapping fields of view and a touch surface encompassed within said overlapping fields of view across which a pointer is moved, wherein the cameras of said at least one pair acquire

images at intervals asynchronously, a method of synchronizing image data acquired by said at least one pair of cameras comprising the step of:

for each camera in said pair:

processing each acquired image to determine the position of said pointer therein and recording the position together with a timestamp representing the time elapsed between a reference point common to said cameras and the time the image was acquired; and

interpolating between pairs of recorded positions to generate interpolated positions and recording each interpolated position together with a synchronization time representing a time each image would have been acquired had said cameras been synchronized.

[0006]   Preferably, the interpolating is performed between each successive pair of recorded positions. The reference point is preferably, a signal sent to each of the cameras simultaneously. A timer associated with each camera is initiated in response to the signal and the value of the timer is read when each image is acquired thereby to determine the timestamp.

[0007]   According to another aspect of the present invention there is provided in a camera-based touch system including at least one pair of cameras having overlapping fields of view and a touch surface encompassed within said overlapping fields of view across which a pointer is moved, wherein the cameras of said at least one pair acquire images at intervals asynchronously, a method of estimating the position of said pointer relative to said touch surface from image data acquired by said at least one pair of cameras, said method comprising the step of:

for each camera in said pair:

processing each acquired image to determine the position of said pointer therein and recording the position together with a timestamp representing the time elapsed between a reference point common to said cameras and the time the image was acquired; and

interpolating between successive pairs of recorded positions to generate interpolated positions and recording said interpolated positions together with synchronization times representing times the images would have been acquired had said cameras been synchronized; and

determining interpolated positions generated by said cameras having equivalent associated synchronization times and triangulating the interpolated positions to estimate the position of the said pointer relative to said touch surface.

[0008]   In accordance with yet another aspect of the present invention there is provided a camera-based touch system comprising:

at least one pair of cameras associated with a touch surface and having overlapping fields of view encompassing said touch surface, said at least one pair of cameras acquiring images of said touch surface from different locations and generating image data;

a processor receiving and processing the image data generated by said at least one pair of cameras to determine the location of an object relative to the touch surface by triangulation when the object is captured in images acquired by the at least one pair of cameras; and

a synchronization mechanism to synchronize image data generated by said at least one pair of cameras.

[0009]   In accordance with still yet another aspect of the present invention there is provided a method of determining the position of a pointer relative to a touch surface comprising the steps of:

acquiring synchronized image data of said touch surface from different locations using cameras having overlapping fields of view; and

processing the image data to yield pointer position data; and

triangulating the pointer position data to determine the position of said pointer relative to said touch surface.

[0010]   The present invention provides advantages in that since the position of the pointer is derived from synchronized camera image data, the pointer position relative to the touch surface can be accurately determined using triangulation. In the case of asynchronously captured images, the pointer position data derived from images is adjusted to approximate pointer position data that would have been derived from the images had the images been synchronously captured. In this manner, the position of the pointer can be accurately determined using triangulation notwithstanding the asynchronous image acquisition.

Brief Description f the Drawings

[0011]   Embodiments of the present invention will now be described more fully with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of a camera-based touch system in accordance with the present invention;

Figure 2 is an isometric view of a touch screen forming part of the touch system of Figure 1;

Figure 3 is an isometric view of a corner portion of the touch screen of Figure 2;

Figure 4 is a schematic diagram of a digital camera forming part of the touch screen of Figure 2;

Figure 5 is a schematic diagram of a master controller forming part of the touch system of Figure 1;

Figure 6 shows triangulation geometry used to calculate a pointer contact position on the touch surface of the touch screen;

Figure 7 is an isometric view of a portion of the touch screen showing how a pair of cameras sees the position of a pointer when the pointer is moved quickly across the touch surface during asynchronous image acquisition; and

Figure 8 is a flowchart showing the steps performed by each camera during x-position adjustment to synthesize camera synchronization.

Detailed Description of the Preferred Embodiment

[0012]   Turning now to Figure 1, a camera-based touch system such as that described in International PCT No. WO 02/03316 filed on July 5, 2001, assigned to the assignee of the present invention, the contents of which are incorporated herein by reference, is shown and is generally identified by reference numeral 50. As can be seen, touch system 50 includes a touch screen 52 coupled to a digital signal processor (DSP) based master controller 54. Master controller 54 is also coupled to a computer 56. Computer 56 executes one or more application programs and provides display output that is presented on the touch screen 52 via a projector 58. The touch screen 52, master controller 54, computer 56 and projector 58 form a closed-loop so that user

contacts with the touch screen 52 can be recorded as writing or drawing or used to control execution of application programs executed by the computer 56.

[0013] Figures 2 to 4 better illustrate the touch screen 52. Touch screen 52 includes a touch surface 60 bordered by a rectangular frame 62. Touch surface 60 is in the form of a rectangular planar sheet of passive material. DSP-based CMOS digital cameras 63_0 to 63_3 are positioned adjacent each corner of the touch screen 52. Each digital camera 63_N is mounted on a frame assembly 64. Each frame assembly 64 includes an angled support plate 66 on which the digital camera 63_N is mounted. Supporting frame elements 70 and 72 are mounted on the plate 66 by way of posts 74 and secure the plate 66 to the frame 62.

[0014] Each digital camera 63_N includes a two-dimensional CMOS image sensor 80 having an associated lens assembly, a first-in-first-out (FIFO) buffer 82 coupled to the image sensor 80 by a data bus and a digital signal processor (DSP) 84 coupled to the FIFO 82 by a data bus and to the image sensor 80 by a control bus. A boot EPROM 86 and a power supply subsystem 88 are also included.

[0015] In the present embodiment, the CMOS camera image sensor 80 is a National LM9617 image sensor configured for a 640x20 pixel subarray that can be operated to capture image frames at rates in excess of 200 frames per second. Arbitrary pixel rows of the image sensor 80 can be selected. Since the pixel rows can be arbitrarily selected, the pixel subarray can be exposed for a greater duration for a given digital camera frame rate providing for good operation in darker rooms in addition to well lit rooms. The FIFO buffer 82 is manufactured by Cypress under part number CY7C4211V and the DSP 84 is manufactured by Analog Devices under part number ADSP2185M.

[0016] The DSP 84 receives and processes image frames from the image sensor 80 to determine the x-positions of a pointer within the image frames. In addition, the DSP 84 provides control information to the image sensor 80 via the control bus. The control information allows the DSP 84 to control parameters of the image sensor 80 such as exposure, gain, array configuration, reset and initialization. The DSP 84 also provides clock signals to the image sensor 80 to control the frame rate of the image sensor 80.

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[0017]   The angle of the plate 66 and the optics of the digital cameras 63_N are selected so that the field of view (FOV) of each digital camera 63_N is slightly beyond 90°. In this way, the entire touch surface 60 is within the field of view of each digital camera 63_N with the field of view of each digital camera 63_N extending slightly beyond a designated peripheral edge of the touch surface 60 as shown in Figure 6.

[0018]   Master controller 54 is best illustrated in Figure 5 and includes a DSP 90, a boot EPROM 92, a serial line driver 94 and a power supply subsystem 95. The DSP 90 communicates with the DSPs 84 of the digital cameras 63_0 to 63_3 over a data bus via a serial port 96 and communicates with the computer 56 over a data bus via a serial port 98 and the serial line driver 94. In this embodiment, the DSP 90 is manufactured by Analog Devices under part number ADSP2185M. The serial line driver 94 is manufactured by Analog Devices under part number ADM222.

[0019]   The master controller 54 and each digital camera 63_N follow a communication protocol that enables bi-directional communications via a common serial cable similar to a universal serial bus (USB). The transmission bandwidth is divided into thirty-two (32) 16-bit channels. Of the thirty-two channels, six (6) channels are assigned to each of the DSPs 84 in the digital cameras 63_0 to 63_3 and to the DSP 90 in the master controller 54 and the remaining two (2) channels are unused. The master controller 54 monitors the twenty-four (24) channels assigned to the DSPs 84. The DSPs 84 monitor the six (6) channels assigned to the DSP 90 of the master controller 54. Communications between the master controller 54 and the digital cameras 63_0 to 63_3 are performed as background processes in response to interrupts.

[0020]   The operation of the touch system 50 will now be described. Initially, a camera offset angle calibration routine is performed to determine the offset angle δ of each digital camera 63_N (see Figure 6). Details of the camera offset angle calibration are described in Applicants' co-pending U.S. Application Serial No. 09,870,698 entitled "Calibrating Camera Offsets to Facilitate Object Position Determination Using Triangulation" filed on June 1, 2001, the content of which is incorporated herein by reference.

[0021]   With the touch system 50 calibrated, each digital camera 63_N acquires image frames of the touch surface 60 within the field of view of its image sensor 80 at a desired frame rate and processes each acquired image frame to determine if a

pointer is in the acquired image frame. During this operation, the DSP 84 reads each image frame from the FIFO buffer 82 and processes the image frame.

[0022]   If a pointer is in the acquired image frame, the image frame is further processed by the DSP 84 to determine the x-position of the pointer. The z-position of

5   the pointer is also determined so that a determination can be made as to whether the pointer is contacting or hovering above the touch surface 60. The x-position data generated by the DSP 84 is then adjusted for camera synchronization purposes, as will be described. Pointer information packets (PIPs) including the pointer position information, status and/or diagnostic information are then generated by the DSP 84

10   and the PIPs are queued for transmission to the master controller 54. The digital cameras 63_0 to 63_3 also receive and respond to command PIPs generated by the master controller 54.

[0023]   The master controller 54 polls the digital cameras 63_0 to 63_3 for PIPs in the queues. In this particular embodiment, the master controller 54 polls the digital

15   cameras at a rate exceeding the image sensor frame rates. Upon receipt of PIPs from the digital cameras 63_N, the master controller 54 examines the PIPs to determine if the PIPs include pointer location data. If the PIPs include pointer location data, the master controller 54 triangulates the pointer location data in the PIPs to determine the position of the pointer relative to the touch surface 60 in Cartesian rectangular

20   coordinates. The master controller 54 in turn transmits calculated pointer position data, status and/or diagnostic information to the computer 56. In this manner, the pointer position data transmitted to the computer 56 can be recorded as writing or drawing or can be used to control execution of application programs executed by the computer 56. The computer 56 also updates the display output conveyed to the

25   projector 58 so that information presented on the touch surface 60 reflects the pointer activity.

[0024]   The master controller 54 also receives commands from the computer 56 and responds accordingly as well as generates and conveys command PIPs to the digital cameras 63_N. Specifics of the manner in which the cameras 63_N determine the

30   pointer x and z positions from the image frame data and create PIPs is described in International PCT Application No. WO 02/03316 and therefore, will not be described herein.

[0025]   When a pointer is stationary on the touch surface 60 or when the pointer is moving slowly across the touch surface 60, the triangulated positions of the pointer relative to the touch surface 60 over time are accurate. However, when the pointer moves quickly across the touch surface 60, a pair of digital cameras 63_N capturing images of the pointer will see the pointer at different positions on the touch surface 60 if the digital cameras 63_N are capturing images at different times. Figure 7 illustrates the above scenario. In this example, camera 63_1 captures images of the pointer slightly ahead of digital camera 63_0. Therefore, as line L is drawn across the touch surface 60, the pointer x-position returned by each digital camera 63_N, each time that digital camera acquires an image, is different. As a result, triangulating the x-positions returned by the digital cameras, results in inaccuracies.

[0026]   Accordingly, to deal with the above problem, in one embodiment of the present invention the camera-based touch system 50 performs synthetic camera synchronization to maintain triangulation accuracy notwithstanding the fact that the digital cameras 63_N acquire images asynchronously. In particular, during synthetic camera synchronization the DSPs 84 in the digital cameras 63_N adjust the x-position data derived from captured image frames to approximate x-position data that would have been derived from the image frames had the image frames been synchronously captured by the digital cameras 63_N. Specifics concerning synthetic camera synchronization will now be described with particular reference to Figure 8.

[0027]   When the DSP 84 in a digital camera 63_N receives an EOF signal from its associated image sensor 80 (step 150), signifying that a new image frame is ready to be read from the FIFO buffer 82, the DSP 84 examines the status of the digital camera 63_N to determine if the digital camera has stalled (step 152). If the camera has not stalled, the value of the DSP internal timer ("TimeStamp") is read and the image frame is processed to determine the x-position of the pointer in the image frame (step 154). The TimeStamp and the pointer x-position form an entry that is used to update a camera history table maintained by the DSP 84 (step 156).

[0028]   At step 152, if the digital camera 63_N has stalled (i.e. image processing for the prior image frame has not been completed by the DSP 84), to avoid losing the TimeStamp read from the DSP internal timer, the x-position is estimated by extrapolating the x-positions of the previous two entries in the camera history table

(step 158). The extrapolated x-position and the TimeStamp form an entry that is used to update the camera history table (step 156). This procedure is considered as error recovery, due to the fact that problems can arise if stalled image frames become frequent or consecutive.

[0029]   Once the camera history table has been updated, the DSP 84 updates a synchronization table maintained by the DSP 84 using the entries in the camera history table (step 162).

[0030]   In the present embodiment, the camera history table includes six entries to ensure that triangulation can be performed even if the digital cameras 63_N become out of phase by four image frames. During updating of the camera history table at step 156, whenever the DSP 84 generates a new x-position and reads the TimeStamp from the DSP internal timer in response to an EOF signal, the DSP 84 rolls the camera history table back by one position. In this manner, the oldest entry in the camera history table at position [0] is discarded and the new entry is placed in the camera history table at position [5].

[0031]   Table 1 below shows camera history tables maintained by the DSPs 84 of digital cameras 63_0 and 63_1. As can be seen, each entry in each of the camera history tables includes a TimeStamp and the associated x-position.

Camera 63_0		Camera 63_1	
TimeStamp	x-position	TimeStamp	x-position
200	10	3700	10
700	20	400	20
1200	30	900	30
1700	40	1400	40
2200	50	1900	50
2700	60	2400	60

[0032]   Table 2 below shows the synchronization tables that are maintained by the DSPs 84 of digital cameras 63_0 and 63_1, based on the camera history tables of Table 1.

SyncTime T_S	Interpolated x-position X_S Camera 63_0	Interpolated x-position X_S Camera 63_1

500	16	22
1000	26	32
1500	36	42
2000	**46**	**52**
2500	56	-
3000	-	-
3500	-	-
4000	-	16

[0033] As can be seen, each entry in the synchronization tables includes a synchronization time T_S and an interpolated x-position X_S. The interpolated x-positions X_S are determined as follows. Assuming that the velocity of the pointer is constant as the pointer travels between two (2) points, the interpolated x-positions are calculated using the equation:

$$X_S = ((X_1 - X_0)/(T_1 - T_0)) * (T_S - T_0) + X_0 \qquad (1)$$

where:

X_0 and X_1 are successive x-position entries in the camera history tables;

T_1 and T_0 are successive TimeStamps corresponding to the x-position entries X_1 and X_0; and

T_S is a given synchronization time, where $T_0 \leq T_s \leq T_1$.

[0034] For example, using the first two entries in the camera history table maintained by digital camera 63_0 shown in Table 1 and a synchronization time T_S equal to 500, equation (1) yields:

$$X_S = ((20 - 10)/(700 - 200)) * (500 - 200) + 10 = 16$$

[0035] In order to interpolate the x-position data accurately, the DSP internal timers need to be calibrated against a common reference. This is due to the fact that the DSP internal timers, although similar, are not identical. As a result, if the DSP internal timers are not reset, a phase error will be introduced. Moreover, the maximum TimeStamp allowable for 16-bit integer math is 32767. If the TimeStamp is permitted to exceed this maximum limit, problems arise. In the present embodiment, a signal embedded in the command PIPs generated by the master

controller 54, that are sent to each of the digital cameras 63_N simultaneously, is used by the digital cameras 63_N to reset the DSP internal timers.

[0036]   Since the DSP internal timers are simultaneously reset, the TimeStamps constitute baseline data that exhibits the following known attributes:

i)   each TimeStamp is greater than its predecessor $(T_1 > T_0)$ except following a DSP internal timer reset; and

ii)   the elapsed time between successive TimeStamps is constant $(C = T_1 - T_0)$ since the camera frame rates are constant.

[0037]   As mentioned above, the attribute $T_1 > T_0$ does not hold true following a DSP internal timer reset. In this case when using equation (1) to calculate the interpolated x-position X_S following a DSP internal timer reset, the term $(T_1 - T_0)$ in equation (1) yields an incorrect and unpredictable value. Thus, when the attribute $T_1 > T_0$ does not hold true, the occurrence of a DSP internal timer reset can be recognized by the DSP 84 allowing TimeStamp T_1 to be corrected prior to performing the interpolation calculation. Since the elapsed time between successive TimeStamps is a known constant C, following a DSP internal timer reset, the TimeStamp T_1 is adjusted by assigning the TimeStamp T_1 a replacement value equal to $C + T_0$.

[0038]   The synchronization times T_S used by each digital camera 63_N during the interpolation calculations are the same and the interval between successive synchronization times T_S is constant. As a result, although the TimeStamps in the camera history tables fluctuate, the synchronization times T_S in the synchronization tables do not. Since the interval between successive synchronization times T_S is also a known constant, following a DSP internal timer reset, the synchronization time T_S can also be corrected so that the term $(T_S - T_0)$ in equation (1) yields a meaningful result during the interpolation calculation.

[0039]   The interval between successive synchronization times T_S should be at least the same as the elapsed time constant C for camera-based touch systems that include only include one pair of cameras. For example, if the elapsed time constant C between T_1 and T_0 is equal to 500, the interval between synchronization times T_S should also be equal to 500. As the number of cameras in the camera-based touch system increases, the interval between synchronization times T_S should be greater than the elapsed time constant C. This results in an increase in the number of non-

redundant interpolated points that are generated by the digital cameras 63_N and hence, an increase in touch system resolution.

[0040] When the digital cameras 63_N are polled by the master controller 54, the digital cameras 63_N package the interpolated x-positions Xs in the synchronization tables into PIPs and convey the PIPs to the master controller 54 (step 164). During polling, the master controller 54 sends a poll number to each digital camera 63_N. The poll number signifies the synchronization time T_s for which an interpolated x-position X_s is desired. If the synchronization table maintained by the DSP 84 of the digital camera 63_N includes an interpolated x-position X_s for the specified synchronization time T_s, the interpolated x-position X_s is packaged into a PIP and the PIP is conveyed to the master controller 54.

[0041] Upon receipt of the PIPs, the master controller 54 uses interpolated x-positions X_S in the PIPs received from pairs of digital cameras having equivilent synchronization times to triangulate the position of the pointer. In the example of Table 2, synchronization time 2000 is the most recent synchronization time at which digital cameras 63_0 and 63_1 will return interpolated x-positions X_S to the master controller 54 if polled for these interpolated x-positions. As a result, these interpolated x-positions X_s can used by the master controller 54 to triangulate the pointer position. Specifics of the triangulation methodology are described in International PCT Application No. WO 02/03316 and therefore, will not be described herein.

[0042] If desired, the camera history tables and the synchronization tables can be maintained by the DSP 90 of the master controller 54 or by the computer 56. In this case, the camera frame rates must be constant and known. Using the DSPs 84 to maintain the camera history tables and the synchronization tables allows the camera frame rates to be variable.

[0043] As an alternate solution to achieve digital camera synchronization, the DSP 84 in each of the digital cameras can be provided with synchronization logic that is responsive to a programmable high-speed signal generator that generates the horizontal and vertical synchronization signals for the camera image sensor 80. The high-speed signal generators are programmed to ensure that each of the digital cameras 63_N captures an image of the touch surface 60 at the same time so that the

images captured by the digital cameras are synchronized. Although this results in synchronized camera images, it is a more costly solution than that of the first embodiment due to the fact that the synchronization logic and programmable high-speed signal generators take up real estate on the digital camera boards and therefore, increase costs.

[0044]   Although the equation (1) interpolates within the interval T_0 to T_1, those of skill in the art will appreciate that it is possible to interpolate outside of the interval T_0 to T_1 although the assumption that the velocity of the pointer is constant during the interpolation interval becomes less true.

[0045]   Although preferred embodiments of the present invention have been described, those of skill in the art will appreciate that variations and modifications may be made without departing from the spirit and scope thereof as defined by the appended claims.